9. *The Acceleration of Earthquake Motion Deduced from Overturning of the Gravestones in Case of the Imaichi Earthquake on Dec. 26, 1949.*

By Ryôhei IKEGAMI and Fuyuhiko KISHINOUYE,

Earthquake Research Institute.

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1. Introduction.

The deductions of acceleration of earthquake motions drawn from the rocking or overturning of gravestones and the destruction of other constructions have played an important rôle in determining the intensity of the great earthquakes in the past. The acceleration was hitherto deduced mostly only from the ratio between height and width of the overturned gravestone, that is to say, *the deduced acceleration of the ground motion=gravitational acceleration×width/height.* But we believe that the deduction of the acceleration drawn only from the ratio between height and width is insufficient, for rocking or overturning of a rectangular column like a gravestone is not only related with this ratio, but also with the dimensions of height and width as shown clearly in our previous paper.[1]

In our field investigations, we often met with cases where gravestones had not overturned because of their large dimensions in spite of the small value of the ratio between height and width. In order to solve this apparently irrational phenomenon in case of the Nankai Earthquake on Dec. 21, 1946, we presented a tentative method.[2] The points of our method are as follows:

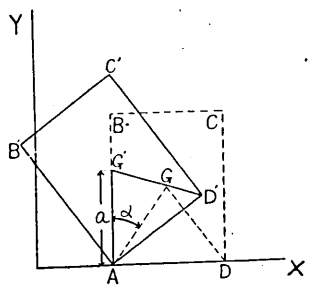

Fig. 1.

The works done by a column, while its center of gravity moves from G to G', (Fig. 1),

$$W_G=Mga(1-\cos\alpha). \quad \cdots\cdots(1).$$

On the other hand, the works done by ground motion, $\varepsilon \sin p(t+\delta)$, to the column are given in the following equation;

1) R. IKEGAMI and F. KISHINOUYE, *Bull. Earthq. Res. Inst.*, 25 (1947), 49.
2) *ditto.*

$$W_D=\frac{a^2M}{6}\left[\frac{m^2p^2}{(n^2+p^2)^2}\left(10+\cosh\frac{n\pi}{p}\right)-\alpha^2n^2\left(2-\cosh\frac{n\pi}{p}\right)\right.$$
$$\left.-\frac{2mn\alpha p}{n^2+p^2}\sinh\frac{n\pi}{p}\right], \quad \cdots\cdots(2)$$

where M is the mass of the column, g the acceleration of gravity, a the length AG, and α the angle $\angle GAB$, and $n^2=\frac{ag}{a^2+k^2}$, $m=\frac{a\varepsilon p^2}{a^2+k^2}$, in which k is the moment of inertia about G, ε and p are the amplitude and the frequency of the given ground motion.

Either overturning or non-overturning of the column due to any given ground motion may be deduced by comparing W_G with W_D. Namely, when $W_G>W_D$, the column is not to be overturned, but when $W_G<W_D$, the column is to be overturned.

2. Estimation of the Acceleration of the Imaichi Earthquake.

In case of the Imaichi Earthquake on Dec. 26, 1949, we could obtain the following data at two graveyards in Imaichi-Machi.

Table I.

Place		width × height	α	a	ratio
		cm. cm.		cm.	
Kawara-Machi, Imaichi-Machi. (A)	overturned	25 × 76	0.318	40.5	0.33
	non-overturned	36 × 128	0.274	66.4	0.28
The vicinity of Shimo-Imaichi Station. (B)	overturned	24 × 66	0.349	35.1	0.35
	non-overturned	36 × 120	0.291	62.6	0.30

These two places are shown in Fig. 2, and one of them is illustrated in Fig. 3.

We applied these values of a and α to the equation $W_G=W_D$, and giving the values of p, calculated the values of ε.

The relations between ε and p at the two places are shown in Figs. 4 and 5 respectively by curves I and II. Curve I is obtained from a and α of the overturned gravestone, and curve II from the non-overturned. When a ground motion expressed by the values of ε and p which correspond to the hatched parts surrounded by curves I and II is given, the high gravestone will not be overturned while the low one will be overturned by it.

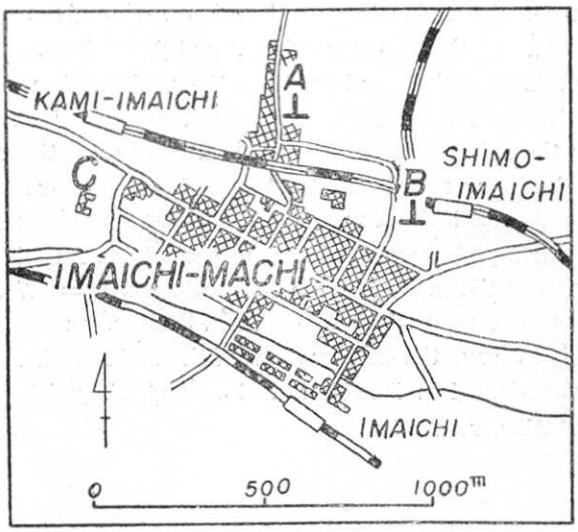

Fig. 2. The map of Imaichi-Machi.
A: The graveyard at Kawara-Machi.
B: The graveyard in the vicinity of Shimo-Imaichi Station.
C: Observation Station of the after-shocks.

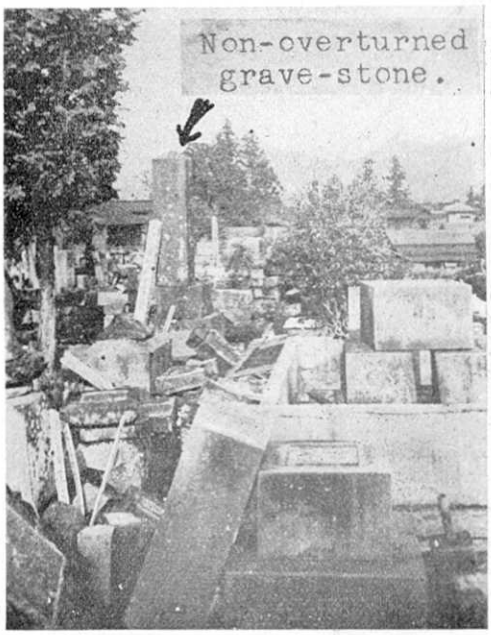

Fig. 3 Non-overturned gravestone, in the graveyard at Kawara-Machi (position A).

But we can not determine the acceleration of the given ground motion uniquely, unless one of the two variables, ε and p, is given. As a means of deducing the periods of the earthquake-motions, the seismograms obtained from the after-shocks of the Imaichi Earthquake recorded at Imaichi-Machi were used. In the seismograms of several after-shocks, the periods of the maximum amplitudes were all about 0.4 seconds. Upon grounds to be mentioned later we deduced the conclusion that the periods of the main-shock of the Imaichi Earthquake were about 0.4 seconds at Imaichi-Machi. If we assume the period of the main-shock to be 0.4 seconds (p=15.7), the values of the amplitude will be computed at 3.70 cm. and 3.85 cm. respectively from Figs. 4 and 5. That is to say, the accelerations of the main-shock are computed at 912 *gal* at Kawara-Machi in Imaichi-Machi and at 949 *gal* in the vicinity of Shimo-Imaichi Station, respectively.

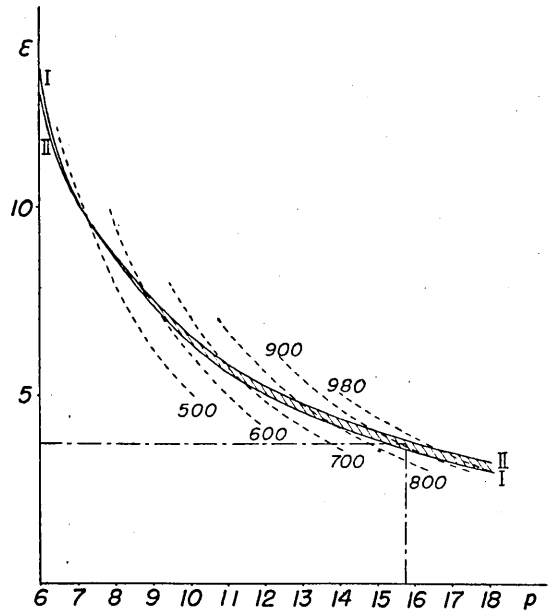

Fig. 4. Curves I and II show the limits of overturning and non-overturning of the gravestone at Kawara-Machi, Imaichi-Machi (position A). Dotted line shows curve of equal acceleration in gal.

Judging from the disaster suffered at Imaichi-Machi, these values of the acceleration may be considered to be overstimated, but the doubt will be dispelled by the following discussion.

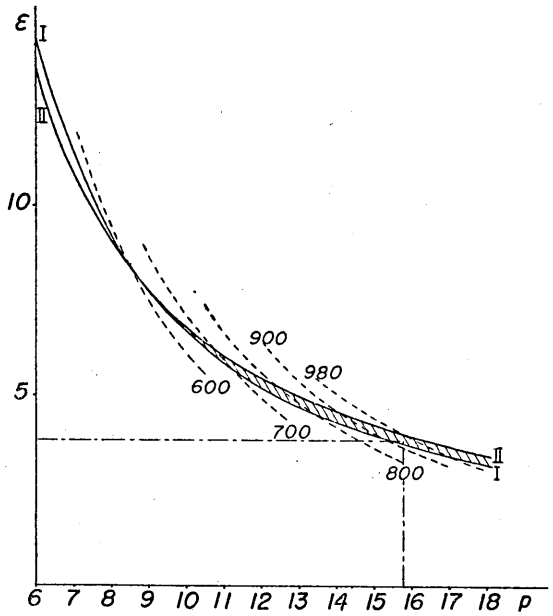

Fig. 5. Curves obtained from the data in the vicinity of Shimo-Imaichi Station (position B).

3. Discussion of the Results.

i) Application of our equations to the data of the Imaichi Earthquake.

Judging from the materials obtained by our field investigations of the Imaichi Earthquake, it seems probable that only one large amplitude or two of the ground motions continued and were damped very rapidly.

If we may consider that the after-shocks of the Imaichi Earthquake had a characteristic in common with the main-shock, we shall be able to identify the characteristic of the seismograms of the after-shocks observed at Imaichi-Machi with this above-mentioned characteristic of the main-shock. By way of illustration, we will show the characteristic in Fig. 6. As recognized from Fig. 6, after the P-phase lasted for a short time, the S-phase with the large amplitude appeared suddenly and repeated only once or twice before they decreased very rapidly. This characteristic of the ground motions accurately corresponds to the assumption in our theory, and we believe that our equations would have applied more precisely to the data of the Imaichi Earthquake than to the data of the Nankai Earthquake.

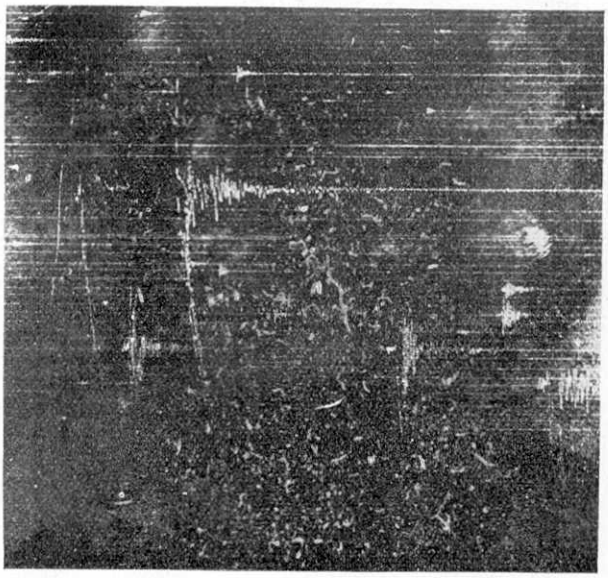

Fig. 6. The seismogram of the after-shocks recorded at Imaichi-Machi (position C).

ii) The doubt on the overestimation of the accelerations.

It was reported as the conclusive results of the field investigations of the Imaichi Earthquake by many investigators that there were scarcely any damages done to wooden houses, but many stone buildings which had been built with piled Ôya-ishi (Tertiary tuff quarried at Ôya, Tochigi Prefecture), were destroyed, which indorses the fact that the periods of the ground motions were rather short and the vibrations of the large amplitudes damped out rapidly. Damage would have been done to many wooden houses, if the ground motions of long periods and large amplitudes had continued for long time, and even in case the ground motions were of large acceleration, unless they continued long, the wooden houses would not be destroyed. Namely, it is probably not unfit to estimate that the maximum acceleration of the Imaichi Earthquake was very large.

iii) A few suggestions for future investigations.

A) It is not a complete estimation to deduce the intensity of earthquakes only from the ratio between the height and width of a gravestone. In case of the Imaichi Earthquake, the ratios of height to width of the overturned gravestones were 0.33 and 0.35, and if we deduce the acceleration as we used to hitherto, the estimated acceleration will be 0.33 g or 0.35 g. That is to say,

we are in danger of underestimating, if the acceleration is deduced only from the ratio. We want to emphasize the necessity to take into account the dimensions of the gravestones in case of determining the acceleration of an earthquake motion.

B) In the past, the intensity of earthquake motion at a certain place was expressed by the value of the acceleration of the ground motion there. But to judge from the above-mentioned fact, we think that the intensity of earthquake at any place can be expressed only incompletely by the value of acceleration. In case of the Imaichi Earthquake, though the deduced accelerations were near gravity, the damages were confined only to stone-buildings. We can deduce from this fact that in spite of the high value of the acceleration, the amplitudes of the ground motions at Imaichi-Machi were small (namely, the periods were short) and the duration of that acceleration was comparatively short.

We think that in future, to estimate the intensity of an earthquake, the amplitude (or the period) of the ground motion and the duration of the acceleration as well as the value of the acceleration must be taken into account at any place.

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9. 昭和24年12月26日今市地震に於ける墓石顚倒より推定した地震動の加速度

地震研究所 池上良平
岸上冬彦

從來大地震の際の加速度推定の資料として顚倒した墓石等を用ひて，その巾と高さの比から推定する事がしばしば行なはれて來た．然し加速度の推定を唯單に墓石の巾と高さとの比のみから行ふ事は不十分であると考へる．即ち大地震後の現地調査にあたつて，我々は比の値が大でもその墓石自身の大きさが小さいために顚倒し，逆に比の値が小であるにも係らずその大きさが大であるために顚倒しなかつた例をしばしば發見するのである．

昭和21年12月21日の南海地震の際にもこの例を海南市と木本市に於て發見し，これを解決する一つの方法を發表した.[1]

今回の今市地震に於ても今市町内の2ケ所（第2圖 A, B）に於てこの例を見出し，前回の方法と同様な取扱ひによつて加速度を推定した．その結果として本震の週期を0.4秒とすると加速度は夫々2ケ所で912ガル及び949ガルとなつた．これらの値は被害程度から考へて一見過大のようであるが，然し次の理由から必ずしもそうでないと考へる．即ち加速度の値が大であつても，振

幅が小（週期が短）であつて且つその加速度を持つた振動が長く續かなければ，木造家屋のような建造物には大して被害はなくてすむと考へられる．事實野外調査の結果今回の地震は大振幅の振動は比較的早く減衰したらしい，又被害を受けた建造物は“大谷石”で積み上げたものや，又は石貼の石造建物が大多數であつて，木造家屋の被害は殆どなかつた事を考へ合せると以上の推定が甚しくは間違つてゐないと考へられる．

以上の事から考へて將來大地震の加速度の推定にあたつては，墓石等の比のみから行ふ事は過小に推定する危險があるから，その墓石自身の大きさも考へに入れて行ふ必要があると考へる．又ある地點での加速度の大きさのみを問題とせず，その繼續時間とか，振幅（又は週期）の大きさ迄も考慮に入れるべきであると考へる．